*Future Directions in High Resolution Astronomy: The 10th Anniversary of the VLBA*
*ASP Conference Series, Vol. ***, 2003*
*J. D. Romney & M. J. Reid (eds.)*



# Where has all the polarization gone?

E. Middelberg, A. L. Roy, U. Bach

*Max-Planck-Institut für Radioastronomie, Bonn, Germany*

D. C. Gabuzda

*Physics Department, University College Cork, Ireland*

T. Beckert

*Max-Planck-Institut für Radioastronomie*

## 1. Introduction

Circumnuclear tori are a central ingredient in the unification of the AGN phenomenon, but the conditions in the tori, the jet collimation, and the accretion mechanisms are still poorly constrained. Magnetic fields are involved in jet collimation and probably in feeding material into the nucleus, but those that are derived using equipartition are uncertain since equipartition conditions are not known to hold.

A more direct measurement of magnetic field strength can be made using Faraday rotation (FR) and free-free absorption (FFA). FR changes the electric vector position angle of a polarized wave passing through a magnetized plasma by an angle $\chi = R_{\mathrm{m}}\,\lambda^2$, where the rotation measure $R_{\mathrm{m}}$ is the path integral over the line-of-sight component of the magnetic field, $B_{\|}$, and the density of thermal electrons, $n_{\mathrm{e}}$. FFA depends on $n_{\mathrm{e}}$, the path length, $L$, and the electron temperature, $T_{\mathrm{e}}$. The value of $L$ can be estimated by assuming it to be the same as the width of the region of FFA in the VLBI images. Making reasonable assumptions about $T_{\mathrm{e}}$, estimates of $n_{\mathrm{e}}$ can also be derived from the FFA measurements. Thus, a joint analysis of FR and FFA measurements can provide direct diagnostics of the magnetic-field strength $B_{\|}$ with minimum imposed assumptions.

## 2. Sample and Results

We selected all five AGNs that we found in the literature that had steeply rising spectra across parts of the jet at pc scales. In all cases, the absorption was most likely FFA due to a pc-scale foreground absorber, perhaps the ionized inner edge of an obscuring torus or an accretion flow. The sample comprises NGC 1052 (LINER), NGC 4261 (FR I), Centaurus A (FR I), Hydra A (FR I) and Cygnus A (FR II). Polarimetric observations were carried out with the VLBA[1] at 15.4 GHz

[1]The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

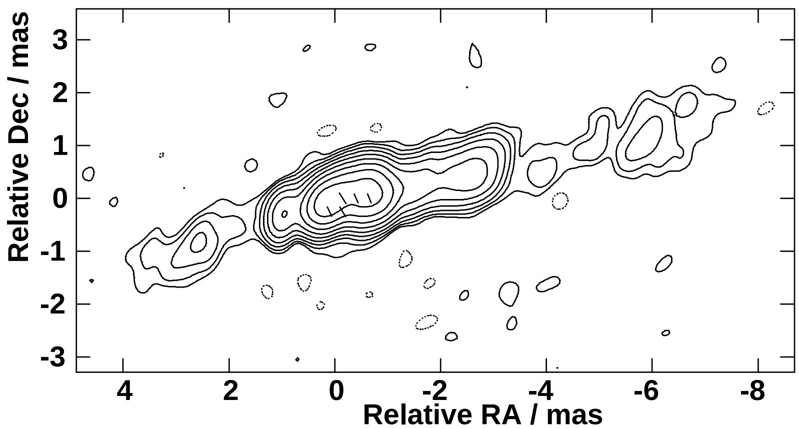


Figure 1. Uniformly weighted 15 GHz image of Cyg A with superimposed polarization vectors.

with 60 min to 240 min integration time per source to see whether polarized emission is present before making FR observations.

Only Cyg A (Fig. 1) showed significant linear polarization, having 1.4 mJy beam$^{-1}$ polarized emission at the position of the total intensity peak flux density of 315 mJy beam$^{-1}$ (0.4 %). With a detection threshold of 0.3 %, all other sources appeared entirely unpolarized, in the absorbed gaps as well as in all other locations along their jets. As the emission process is undoubtedly synchrotron emission (given the high brightness temperatures), the lack of polarized emission in these sources needs explanation.

## 3. Discussion

We suggest several intrinsic and extrinsic mechanisms to depolarize the emission.

**Tangled internal magnetic fields:** Assume the source is optically thin and its magnetic field is composed of a uniform component $B_0$ and a random component $B_\mathrm{r}$. Provided that $B_\mathrm{r}$ varies on scales much less than the source diameter and that the electrons have a power-law energy distribution with index $\gamma$, the intrinsic degree of polarization $p(\gamma)$ will be averaged over the source to $p_i = p(\gamma)(B_0^2)/(B_0^2 + B_r^2)$ (Burn 1966). For $\gamma = 2$, the intrinsic degree of polarization is 70 %. To depolarize this below our detection threshold, the magnetic field energy would need to be extremely dominated by the random component, and so the jets would have to be turbulent, and very little ordering of the magnetic fields by the overall outward motion of the jet flow would be permitted. In case the source is optically thick, the maximum intrinsic degree of polarization is 10 % to 12 %, and we receive emission only from the surface. For the source to appear depolarized, the scale on which the surface magnetic field is tangled must be much smaller ($< 1/10$) than the observing beam. This explanation is unsatisfactory because the magnetic fields inside the jets must be ordered to confine them, but the surface must be turbulent, and why the transition occurs is unexplained.

**Internal Faraday rotation:** In the transition region between optically thick and optically thin source parts, internal FR could be significant. Polarized emission from various depths along the line of sight through the source are Faraday rotated by the source itself, the degree of rotation depending on the depth of the emitting region. However, internal FR is also unsatisfactory for explaining our observed lack of polarization because it requires a significant fraction of "cold" ($\Gamma_{\rm min} \approx 1 - 10$) electrons in the jet. Internal FR produces a characteristic dependence of polarization fraction on frequency, but unfortunately, we are not able to test for the expected wavelength dependence because we lack the required measurements of the polarization fraction at several wavelengths.

**Bandwidth depolarization:** This depolarization mechanism requires very high, homogeneous RM ($10^6\,\mathrm{rad\,m^{-2}}$), and such conditions should also produce strong FFA which is not seen along most of the depolarized jets. A possible way out is if the Faraday screen/absorber is very extended or hot, or both.

**Beam depolarization:** If the magnetic field in a foreground Faraday screen is tangled on scales much smaller than the observing beam, regions with similar degrees of polarization but opposite signs will average out and the observed degree of polarization will be decreased. Thus, with spatially highly variable RM, one could in principle depolarize the source, although the *changes* in RM from region to region still need to be of the order of $10^4\,\mathrm{rad\,m^{-2}}$ to depolarize the 15 GHz band. If one requires at least 10 cells across the beam, the typical cell sizes in NGC 1052, NGC 4261, Cen A, Hyd A and Cyg A need to be 0.01 pc, 0.02 pc, 0.002 pc, 0.12 pc and 0.13 pc, respectively. Since these are the least exotic conditions required by any of the mechanisms discussed, we feel that beam depolarization in an external medium is the most likely mechanism to depolarize the sources presented here.

## 4. Summary

Compact core-dominated AGN such as BL Lac objects and quasars typically display linear polarization of a few to a few tens of percent on pc scales, with the degree of polarization occasionally approaching the theoretical maximum of 70 %. Thus, some AGN jets have comparatively modest depolarization. In contrast, the pc-scale structures of the five radio sources considered here exhibit strong depolarization at high frequencies. The weakness of their pc-scale polarization indicates that most likely tangled jet magnetic fields on sub-pc scales in a foreground screen causes beam depolarization, although we lack enough information to conclusively decide among the discussed mechanisms. Why that screen is present in these objects but absent in most core-dominated AGNs might be an orientation-selection effect. Core-dominated objects are viewed preferentially pole-on, and then the lack of depolarization means that the Faraday screen lies in the equatorial plane. The sample of jets selected here is viewed preferentially face-on, making the Faraday-screen viewed against the source.

## References

Burn, B. J. 1966, MNRAS, 133, 67